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# Hohlraum Characterization Milestones

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#### ABSTRACT

A successful ignition campaign will depend in part upon having highly characterized hohlraums and shells for target assemblies. Regarding hohlraums, properties of interest include dimensions, surface features and chemical composition. This report outlines the metrology needs for hohlraums and provides a timeline for capital as well as FTE expenditures through '07. The topics discussed include hohlraum metrology, windows and tenting metrology, with comments on support of other areas including cryo-related development efforts. Although there is a strong interest in non-destructive characterization, this report also investigates the use of destructive techniques for providing critical information for process development and improvement.

#### I. INTRODUCTION

NIF hohlraum production involves a large number of procedures where regular metrology and inspection is required. A flowchart indicating the various aspects of the hohlraum development process is shown in Figure 1. Only two metrology steps were indicated in this initial plan. Those included metrology after hohlraum halves are constructed and another after tent films are obtained but before they are inserted into the target. As can be seen in the flow chart, there are many steps where some type of quality control check is needed before the various parts are inserted into the assembly. In addition, milestone WBS 4.3.6.1 indicated that there were (at the time) several areas of interest in terms of component metrology. Those are shown in Figure 2. The first two categories, hohlraum metrology and windows/tenting metrology, fit naturally into a characterization program and will be discussed in more detail later in this report. The other items in WBS 4.3.6.1, specifically hohlraum mount testing, cryo add-ons, and IR diagnostic profiling fit more naturally into a manufacturing and assembly program.

The characterization issues described in this report can be divided into two categories. The first comprises those things that will become significant and independent milestones. The second consists of issues that will exist primarily to support other milestones in related efforts.

This memo serves not only to indicate what the characterization needs will be through FY'07, but also to describe the associated

techniques in detail. Appendix 1 will provide an overview and justification for the techniques that will be used to support hohlraum characterization over this time frame. Specifications for dimensional and compositional requirements were all taken from a paper by Stephens, Haan, and Wilson. [Characterization Specifications for Baseline Indirect Drive NIF Targets, R.B. Stephens, S.W. Haan, and D.C. Wilson, *Fusion Science and Technology* **41**, 226, 2002]

## II. HOHLRAUM DIMENSIONS, WALL THICKNESS AND COMPOSITION

A flowchart for basic hohlraum characterization is shown in Figure 3. This indicates what characterization techniques are needed at various points of the process. Additionally, it outlines which areas require further development.

### A. DIMENSIONS

These measurements are currently being performed by General Atomics. The length should be 5 to 15mm, the body diameter around 6mm and the laser entrance holes around 3mm diameter. The dimensions should be measured to less than 10  $\mu\text{m}$ . The cylindrical deviation of the inner wall should be less than 10  $\mu\text{m}$ . Features on the inside of the hohlraum wall should be measured with a  $\sim 10$   $\mu\text{m}$  precision. The measurements are relatively straightforward. The hohlraum diameter is measured with a laser micrometer. The length is measured with a traveling microscope, also known as a machinist's microscope. The traveling microscopes have accuracies of a few microns. Both instruments are able to provide data to satisfy the current tolerances. An SEM is currently used to measure cracks, tubes, steps and other features on the hohlraum wall. The data provided in this case is solely 2D. If lateral dimensions alone are sufficient then SEM is a fast and convenient tool for these measurements. However, if it is determined that depth or height measurements are needed, then optical profilometry would be a better technique to use. A WYKO optical profiler exists at G.A. and could be used for such measurements. This is a convenient technique in that it can measure 3D topography on concave surfaces. Such measurements can be more difficult to do with other methods such as Atomic Force Microscopy (AFM). The latter is limited in a geometric sense in that the cantilever that travels over the surface will not necessarily fit into a concave surface. In addition to that, the dynamic range of the instrument is generally in the 5-8  $\mu\text{m}$  range. If the height of the feature of interest is large

compared to the maximum scan size, then there may not be enough dynamic range to capture all of the 3D information.

One area where further development is required is in monitoring the deviations in the outer wall of the hohlraum. After electroplating, bulges sometimes develop around the corners of the wall. This may present a problem for cryo hohlraums because of the resulting asymmetry in thermal characteristics. The radius should be measured as a function of distance along the cylindrical axis and with angular position ( $\theta$ ). Although a detailed analysis has not yet been made, it is felt that up to 10% deviations in the wall shape can be tolerated.

#### B. WALL THICKNESS

The thickness of the high-Z layer is determined by measuring the diameter of the mandrel before and after deposition of this layer. The measurements are made with a laser micrometer. This is a straightforward measurement and no further development is anticipated. The thickness of the high-Z material in the inner wall is on the order of 20 $\mu\text{m}$  and the thickness should be measured to within less than 0.5 $\mu\text{m}$  if the high-Z material in the wall is thinner than 10 $\mu\text{m}$ . Thickness as a function of both angular position and distance along the cylindrical axis should be measured.

#### C. COMPOSITION

The composition of the hohlraums is currently being measured by G.A. using an SEM equipped with a detector for Energy Dispersive X-ray Analysis. (EDX). This technique is convenient to use in the sense that the spectroscopy and imaging can be carried out with the same instrument. At the moment, the EDX is being used to measure composition and to look for high-Z contaminants. However, the information provided, in terms of chemical composition, is qualitative in nature. A more quantitative technique is needed, particularly if cocktail hohlraums become a standard part of target fabrication.

Regarding cocktail hohlraums, the current system is designed to co-sputter the materials and create a uniform coating of U:Nb<sub>0.14</sub>:Au:Ta:Dy or U:Nb<sub>0.14</sub>:Au:Dy. In terms of characterization, there are several critical needs. One of those would be to have a reliable and routine way to measure the composition quantitatively and to 5% for each element in the coating. This could be done with a technique known as Electron Probe

Microanalysis (EPMA). This is an analytical technique that combines high-resolution SEM imaging with quantitative and non-destructive elemental analysis of materials. This instrument can accommodate a wide variety of solid materials, including metals, ceramics, semiconductors, glasses and polymers. For the latter, which are generally non-conductive, a coating of Au or C is required. The detectable element range encompasses Be to U with detection limits of 10's to 100's of ppm. Quantitative information is obtained by making measurements on high purity elemental standards. The observed x-ray intensities are then converted to atomic concentrations using a CITZAF algorithm. An EPMA exists at LLNL within the Institute of Geophysics and Planetary Physics group. The EPMA would provide *quantitative* information on the cocktail composition and could also be used to verify the compositional uniformity, in a lateral sense, by doing line or 2D scans. The analysis depth varies with experimental conditions and specific element in question, but is generally on the order of a few microns. Discussions with the cocktail hohlraum working group indicate that it is these first several microns that are of the greatest concern with respect to such things as oxygen content.

Another area of critical importance to cocktail hohlraum development would be to study oxidation behavior. There is an interest in knowing what the overall oxygen content is, both initially and over time as the hohlraum awaits assembly. In addition to that, there is also an interest in knowing what the oxygen profile is, if it does in fact exist. A critical need for FY'05 is to determine what characterization tools should be used to study oxidation behavior in cocktail hohlraums and to create and analyze prototypes of a U:Nb<sub>0.14</sub>:Au:Ta:Dy or U:Nb<sub>0.14</sub>:Au:Dy material co-sputtered onto mandrels. Initially, one could produce two mandrels, one that will be examined "as-is" and the other which will be subjected to the same treatment that is normally used with actual hohlraums. The latter will provide insight into the contributions of the leaching process to subsequent oxidation behavior. The samples will be examined via EPMA to determine overall oxygen content both with and without the leaching step. If an oxygen content is present, then the samples will be examined with Secondary Ion Mass Spectrometry (SIMS) to produce depth profiles so that the location of the oxygen can be determined. The same samples will also be re-examined with both EPMA and SIMS at several intervals over a two-week time frame which is the typically storage period. This will provide some information on how problematic the oxidation is and what is reasonable in terms of storage times and methods. Concurrently, it will be critical to maintain interaction with designers to determine what is an acceptable level of oxidation

in these materials. It is well known that some of the potential cocktail materials, such as Dysprosium, oxidize fairly rapidly and are usually not available in pure form. So there may always be some amount of oxide. Specifications will need to be made as to what is an acceptable amount.

For the actual cocktail hohlraums where the total thickness is on the order of 10's of  $\mu\text{m}$ , it may be necessary to use a slightly different technique to determine overall oxygen content since EPMA usually only examines the top 1-2  $\mu\text{m}$ . Another technique that could be used to profile through a layer, say 10-20  $\mu\text{m}$  thick would be Rutherford Back Scattering (non-destructive) or SIMS (destructive).

The next stage of cocktail hohlraum design will be to produce alternating layers of the same elements used in the original coatings, i.e. a layer of  $\text{U:Nb}_{0.14}$  followed by a layer of Au and Dy, etc. One item that still needs to be determined, which will affect the characterization methods used, is the thickness and number of these layers. The current thought is that there should be 100's of layers, each approximately 100 Å to 200 Å thick. Whether or not the coating system can accommodate this is still to be determined. It is a potential complicating factor since most techniques do not have a depth resolution sufficient to detect such thin layers. Rutherford Back Scattering can do non-destructive depth profiling up to a wall thickness of 80-100  $\mu\text{m}$ , but the depth resolution is on the order of  $\mu\text{m}$ 's. Techniques such as EPMA in this case would provide overall averages. The best characterization method to use for the layered cocktail hohlraums would be SIMS. The depth profiles could be made on a nm to atomic level and thus, the layer thicknesses could be obtained. The primary caveat to this would be determining relative efficiency factors to obtain depth profiles. However, it is a technique worth investigating further.

### III TENTING METROLOGY

This particular aspect of hohlraum fabrication and characterization is in need of considerable development. Although each of the individual measurements (dimensions, composition, thickness) is relatively straightforward *before* the tent is applied, it is a more difficult problem to investigate *after* the fact. A flowchart for tenting metrology is shown in Figure 4 to indicate what areas and techniques are currently

being investigated and where new characterization techniques are needed.

#### A. DIMENSIONS

The initial thickness is measured by profilometry before the tent is stretched onto the capsule. No further development is anticipated.

#### B. COMPOSITION

This is not being done currently. There is an interest in doing a quantitative analysis, primarily to look for any high-Z contaminants. The information would need to be made to within 5% of each element. This could be done on films relatively easily with a number of different techniques, including XRF, EPMA, or XPS, all techniques which are available at LLNL.

#### C. SURFACE ROUGHNESS

This is not currently being measured. This is a straightforward measurement to do before the sample is stretched onto the capsule. Although films that are spincast onto silicon wafers should be smooth, this should be verified. Ideal characterization techniques for this would be AFM and interferometry. Both instruments are available at LLNL.

#### D. DIMENSION AND SURFACE ROUGHNESS MEASUREMENTS AFTER TENT IS STRETCHED ONTO CAPSULE

This is an area that requires considerable characterization technique development. It is not currently known how the thickness and surface characteristics of the tent film change after it is stretched onto the capsule. Not only is information needed on the thickness after stretching, but also on surface roughness, including information on any wrinkling that might be present. This is not a simple and straightforward problem because the measurements need to be made when the capsule is suspended in the hohlraum. It is possible that some type of interferometry could be used but it may need considerable modification to accommodate the sample geometry. However, the situation may become simplified if the hohlraum is made in a two-part design with a ring in the middle where the capsule would be suspended between tent films. This would simplify such measurements considerably. This is a characterization problem that should become a significant development milestone for FY'05.



#### IV. WINDOWS METROLOGY

A flowchart for characterization issues related to windows is shown in Figure 5. It is evident that very little characterization work is being performed. These measurements are straightforward and can be carried out before the windows are inserted into the hohlraum assembly. No major development work is anticipated.

##### A. Dimensions

The window dimensions (i.e. thickness) is currently measured by Schaeffer corporation with an interferometer. No further development is required.

##### B. CHEMICAL COMPOSITION.

The chemical composition is not currently being measured. A quantitative analysis is needed with measurements of high-Z contaminants to within 5%. This could be done using the same techniques that will be investigated for analyzing the chemical composition of the tents. (XRF, EPMA or XPS).

##### C. SURFACE ROUGHNESS

The surface roughness of free standing films could be measured with an interferometer, such as the WYKO instrument at LLNL. However, it is not anticipated that such measurements would be needed.

#### V. BAFFLE METROLOGY

The current situation for baffles is similar to that of windows and tents. The film thickness (via profilometry in this case) is the only quantity being measured. Composition and surface

roughness are not being measured but could be done in a manner similar to that of both windows and tents. A characterization flowchart for this component is shown in Figure 6.

#### A. DIMENSIONS

The thickness is measured with profilometry and no further development is expected.

#### B. COMPOSITION

Not currently being measured, but should be examined with a technique such as XRF, EPMA or XPS.

#### C. SURFACE ROUGHNESS

Such measurements are probably not needed.

#### D. MEASUREMENTS AFTER BAFFLE IS INSERTED INTO HOHLRAUM ASSEMBLY

The exact method of baffle insertion is still to be determined. This will necessarily have an impact on how surface roughness is measured after the baffle is inserted into the hohlraum assembly. This may not necessarily be a straightforward characterization problem. One would be dealing with characterizing a free-standing film that has other components in the way. Characterizing such an assembly with AFM would probably not work due to clearance issues with the cantilever beam. The most likely candidate would be interferometry. Since the geometric issues and constraints here would be similar to that of item IIID (tent metrology), the characterization technique development effort could be combined. The information needed here would be on grosser characterization issues such as folds and holes rather than fine detail on surface roughness.

### VI. MISCELLANEOUS HOHLRAUM CHARACTERIZATION

The hohlraum components listed in items I-V are ones where some type of characterization development is required along with subsequent milestone reporting. The items listed in this section

are not ones that necessarily require separate characterization milestones, but support other critical efforts and are thus important to mention.

#### A. HEATING COILS

This is a considerable development effort taking place with respect to heating coils. A prototype of a new design with patterned heating coils on a test mandrel is shown in a stereo microscope image in Figure 7. An additional set of images taken at high magnification with an SEM are shown in Figure 8. The current design that will be replaced is shown in Figure 8D, to indicate where the patterned traces will eventually go. These initial images suggest that optical and SEM characterization would be essential tools to use during the development process. It is clear from the first three images (8A-C) that there are quality control issues with respect to the quality of the Cu lines and the bonding with the mandrel. In 8A and 8B there are many stray particles which suggests that the photoresist removal process isn't as thorough as it needs to be. Stray particles such as these could cause shorts. The image in 8C shows that there is poor bonding to the substrate. It may very well be that a bonding layer will need to be deposited first. If that is the case, then SEM should be employed to look at the surfaces at high resolution to help assess the bonding quality.

#### B. COOLING RINGS

Like the heating coils, the cooling rings are also undergoing considerable development. A new design is shown in Figure 9. The new design is shown at the top of the page. Its location within a cryo hohlraum assembly is indicated in the second image. High magnification images taken with SEM are shown in Figure 10. The SEM images can be used to verify dimension specifications. It is expected at this point that no characterization technique development would be required. Rather, the characterization would be routine work carried out at various points in the process for quality control purposes.

### VII. HOHLRAUM CHARACTERIZATION TIMELINE

The timeline in Figure 11 indicates what will be done in FY'05 and FY'06 for hohlraum characterization development. All the specifications will be defined in the first few quarters of FY'05. The first major development effort, that of fabricating and characterizing mock cocktail hohlraums, will be carried out by the end of FY'05. The second major developmental effort, design of a system for measuring tent, window and baffle surface roughness in-situ will be carried out in FY'06, but may start earlier if sufficient FTE time is available.

Most of the expenses related to development activities involve instrument time rather than procurement. It is anticipated that we will need at least the equivalent of 1/2 FTE in FY'05 and FY'06 to cover these expenses (operator time). Procurement in FY' 05 will fall in the \$30-50k range and will include a 12-bit cooled CCD camera, backup parts and extra X-Ray tube for the XRF instrument in B298 and miscellaneous funds for upgrading the 2D contact radiography system also in B298. By the end of FY '05 we will need to spend \$150-\$200k for a new interferometry system to replace the current one. Not only will support of this instrument end during Q4 of FY'05, but it may not be suitable for the in-situ measurements that tent, window and baffle characterization will require. Some modifications may be necessary. The range associated with this particular procurement item is meant to address the extra expense associated with modifying a new instrument for the aforementioned purposes.

## **Summary of Additional Characterization Techniques of Interest for Hohlraum Metrology**

A comparison of various analytical techniques is shown in Figure 12. Indicated in the chart are the elements analyzed, the detection limit, depth resolution and probe size (lateral resolution). This information is also depicted pictorially in the schematic in Figure 13 specifically for comparing analysis depths.

### **ELECTRON PROBE MICROANALYSIS:**

Electron Probe Microanalysis (EPMA) is an analytical technique that combines high-resolution SEM imaging with quantitative and non-destructive elemental analysis of materials. This instrument can accommodate a wide variety of solid materials, including metals, ceramics, semiconductors, glasses and polymers. For the latter, which are generally non-conductive, a coating of Au or C is required. The detectable element range encompasses Be to U with detection limits of 10's to 100's of ppm. The sampling volume depends on the accelerating voltage, but is typically around 1-2  $\mu\text{m}$  for most samples.

In this technique, incident electrons ionize the sample and produce a vacancy in the inner shell. When the atom decays from its excited state, it produces either a characteristic photon (x-ray fluorescence) or electron (secondary or backscattered). A number of different detectors are used to produce various types of images. Images of the sample surface are obtained through use of the backscattered and secondary electron detectors. The backscattered electrons are generated from deeper within the sample and contain information primarily on chemical contrast. The secondary electrons, on the other hand, escape from the near surface regions and contain primarily topographical information. This is depicted graphically in the schematic of Figure 14.

Characteristic photons that are emitted can be analyzed two ways, either with energy dispersive spectroscopy (EDS) or wavelength dispersive spectroscopy (WDS). There are a number of advantages and disadvantages for each of the techniques, with EPMA/WDS being the superior combination for quantitative chemical analysis. In EDS, only one detector is used to collect the entire

spectrum and the detector is generally placed closer to the sample. As a result, the collection times are shorter and the collection efficiency is larger. However, the spectral resolution for EDS is not as good. Peaks are much broader, peak to background ratios are higher, count rates are lower and peak overlap can make it more difficult to do detection and quantification. Thus, EDS is more appropriate for doing a fast qualitative analysis. When quantifying the amount of a particular element is critical, then WDS is the preferred detection method. A comparison of EDS and WDS with respect to fundamental parameters such as collection efficiency, quantum efficiency, spectral resolution, etc. are shown in Figure 15.

## **SECONDARY ION MASS SPECTROMETRY (SIMS)**

In the SIMS technique, a solid sample is sputtered by primary ions with an energy in the few keV range. A certain percentage of the particles emitted from the target are ionized and analyzed with a mass spectrometer. SIMS is widely used for analyzing trace elements in materials and in dynamic mode for producing depth profiles. This technique can provide both elemental, isotopic and molecular composition information. The range of detectable elements is quite broad and ranges from hydrogen to Uranium. The detection limit is as low as the ppb level for many elements. The lateral resolution is typically on the micron level, but can be as low as the 50nm range in instruments such as the nano-SIMS. A map of molecular species distribution can also be obtained by scanning the ion beam.

In ion beam sputtering, the primary ion beam impinges on the surface and produces a variety of species, including monatomic and polyatomic particles from the sample, resputtered primary ions as well as photons and electrons. The secondary particles can have negative, positive or neutral charges. The kinetic energies are in the range of zero to hundreds of eV. A schematic depicting these mechanisms is shown in Figure 16. Species used for the primary ion beam typically include  $\text{Cs}^+$ ,  $\text{O}_2^+$ ,  $\text{O}^+$ ,  $\text{Ar}^+$  and  $\text{Ga}^+$  with energies in the 1 to 30 keV range. Sampling depth is 1 to 10nm. The sputter yield, which is a ratio of the number of sputtered atoms to the number of primary ions, is in the

5 to 15 range. This number depends upon a number of factors, including chemical environment and sputtering conditions. The latter is a function of primary ion type, primary ion energy and sputtering angle.

Quantification of the SIMS data is not necessarily an easy problem because the conversion from ion intensity to concentration requires the use of relative sensitivity factors as shown in the following equation:

$$C_E = \frac{RSF_E \cdot I_E C_M}{I_M}$$

where

$C_E$  is the concentration of the element E (typically a trace element)

$RSF_E$  is the relative sensitivity factor for E

$I_E$  is the secondary ion intensity for E

$C_M$  is the concentration of matrix element M

$I_M$  = secondary ion intensity for matrix element M

Since the ion yield depends on several factors, including the primary ion type, the matrix element and the analyte element, RSF's must be measured for each one. This is typically done by using ion-implanted standards where a known amount of element E is implanted into matrix M. Then by knowing the depth of the sputtered area and the sputtering rate, the plot of secondary ions as a function of time can be converted to a plot of concentration as a function of distance. Extensive data has been tabulated for RSF's of a wide range of elements in common matrices such as Silicon. If the RSF's for Si are substituted for acquisition of the actual RSF's, the resulting concentration values would be off by a factor in the 5% range.

Secondary ion intensities can be acquired as a function of position to create chemical/molecular species maps. By combining this feature with depth profiling, one can create a 3D model of the species distribution.

OPTICAL PROFILING/WHITE LIGHT INTERFEROMETRY:

This is a non-contact and non-destructive technique for measuring surface morphology from millimeter down to nanometer scale features. It can also be used for measuring film thickness in the range of 8mm to 50nm. Optical profiling offers several advantages over other techniques for measuring both topography and film thickness. Regarding morphology, optical profiling can provide details on surfaces that are unreachable with other probes. One example of this would be concave surfaces such as the interior of a cylinder or sphere. These are very difficult and oftentimes impossible to image with Atomic Force Microscopy (AFM), which is usually the instrument of choice for measurements of surface roughness. In addition, the optical profiler can image areas up to 8x8 mm unlike AFM, which is typically limited to 100x100  $\mu\text{m}$  areas. For measuring thickness, the dynamic range of an optical profiler is much greater than that of an ellipsometer. The later is typically limited to a range of a few microns and only works on dielectric materials. An optical profiler can be used to analyze both metallic and non-metallic films.

Optical profilers use one of two methods to determine variations in surface height, Phase Shifting Interferometry (PSI) and Vertical Scanning Interferometry (VSI). The PSI method is generally used for high volume applications where fast scanning is needed. It is also used for cases where very high precision vertical measurements are critical, such as for optical flats and wafers. These vertical measurements can be made at a sub-nanometer resolution. However, PSI is not good at measuring step-like changes or features with height variations where adjacent pixels exceed 1/4 of the wavelength used. The VSI method, on the other hand, is better at measuring discontinuities and rough features such as islands and cavities. However, measurement times are longer, in the several seconds to minute range compared with fractions of a second for PSI. The vertical resolution is also lower, in the single nanometer range rather than sub-nanometer of the PSI method. There are times when both methods are needed in a single experiment, in which case, a new method called Enhanced Vertical Scanning Interferometry (EVSI) can be used. This approach combines the resolution of the PSI measurements with the vertical scan range of the VSI technique.



The EVSI technique would be particularly useful for the demanding range of NIF/ICF applications and high precision requirements, particularly for target design.

#### X-RAY FLUORESCENCE:

X-ray fluorescence is a non-destructive technique used for elemental analysis.

In this technique, an inner shell electron is excited by an incident photon in the X-ray region. During the following de-excitation process, an electron moves from a higher level to fill the vacancy. The energy difference between the two shells manifests itself as an X-ray that is emitted by the atom. A schematic showing these mechanisms is shown in Figure 17. The resulting secondary/fluorescent x-rays are analyzed in terms of energy and number to identify elements and their concentrations. It is a bulk technique with an analysis depth from 1cm to below 1mm, depending on the energy of the source and the composition of the sample. Depending on the specific conditions used in the experiment, the instrument can detect a wide range of elements, from Be to U. The sensitivities are in the ppm range, with typical values as follows:

Na-Mg:	20-50ppm
Al-Ti:	5-10ppm
V-U:	1-5ppm

The precision is usually 1% or better for most elements. The accuracy depends on the method used. For analysis without standards, the accuracy is in the 10-20% range. For analysis via fundamental parameters, the range is 2-10% and for empirical, it is 3-5%. XRF is a relatively fast technique with analysis time ranging from 30 minutes down to a few seconds. Another advantage of this technique is that very little sample preparation is required and many types of samples can be analyzed including metals, polymers, slurries and even liquids. Samples do not need to be conductive, so there is no need for coating as there is with other techniques such as SEM and Electron probe. Obtaining accurate quantitative information depends in part upon having an accurate geometric model. The XRF technique is best suited for measurements on flat samples. Custom designed analysis programs need to be developed to get

accurate quantitative results on other geometries. Nevertheless, its speed and non-destructive nature make it a particularly useful instrument for quickly identifying elemental impurities in solid samples, something of significant interest for addressing NIF materials specifications.

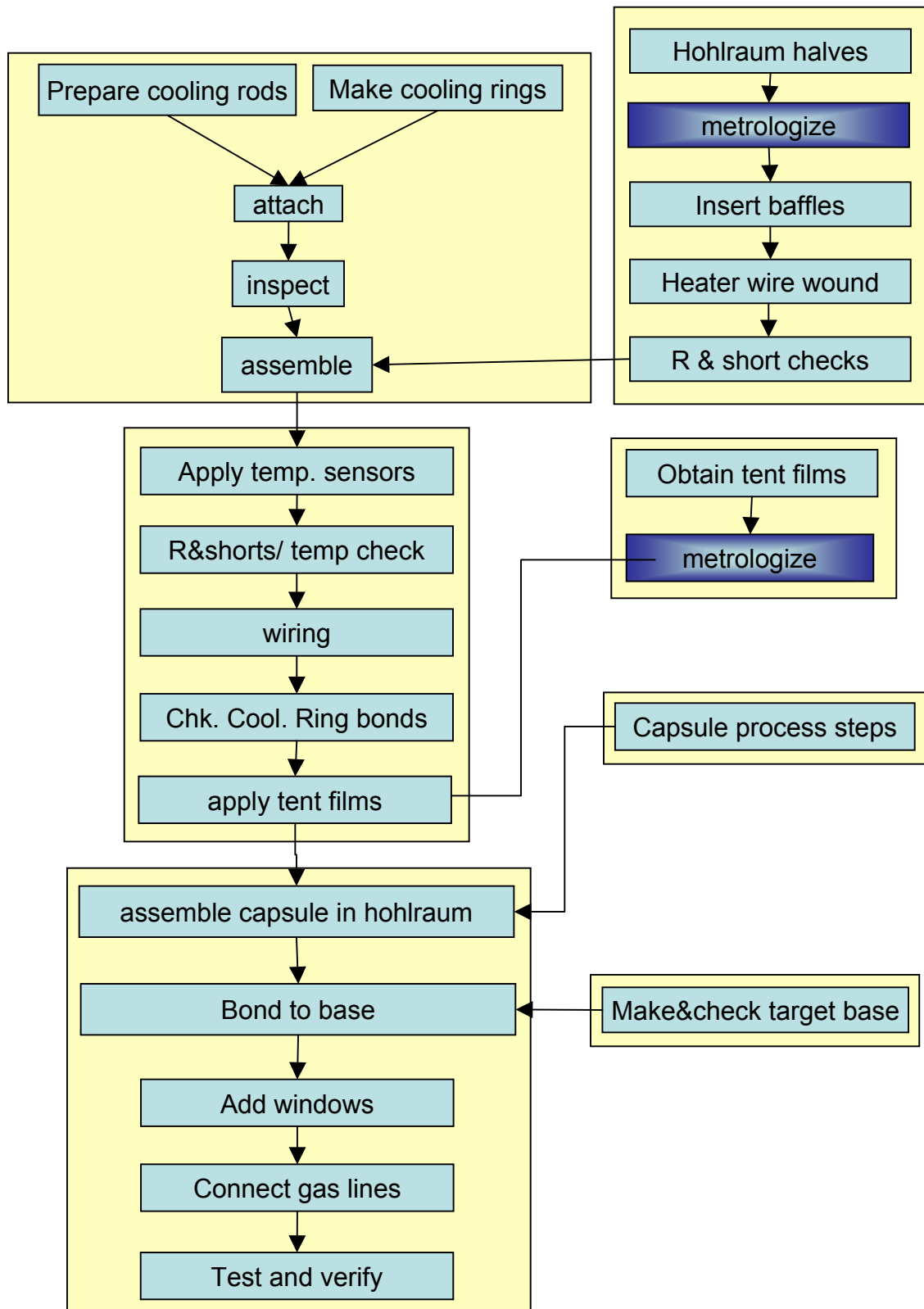


Figure 1: Original flowchart showing process steps and original groupings for Ignition Target Production

## WBS 4.3.6.1 Component Metrology

Hohlraum metrology	Dimensions, wall thickness, composition
Windows/tenting metrology	Dimensions, thickness, composition, surface roughness
Hohlraum mount testing	Vibration sensitivity, static deflection
Cryo add-ons metrology	Heater power capability Room temperature IR symmetry
IR Diagnostic profiling	Temperature sensor calibration

Figure 2: Listing of the components of milestone WBS 4.3.6.1  
The original list of areas of interest for component metrology

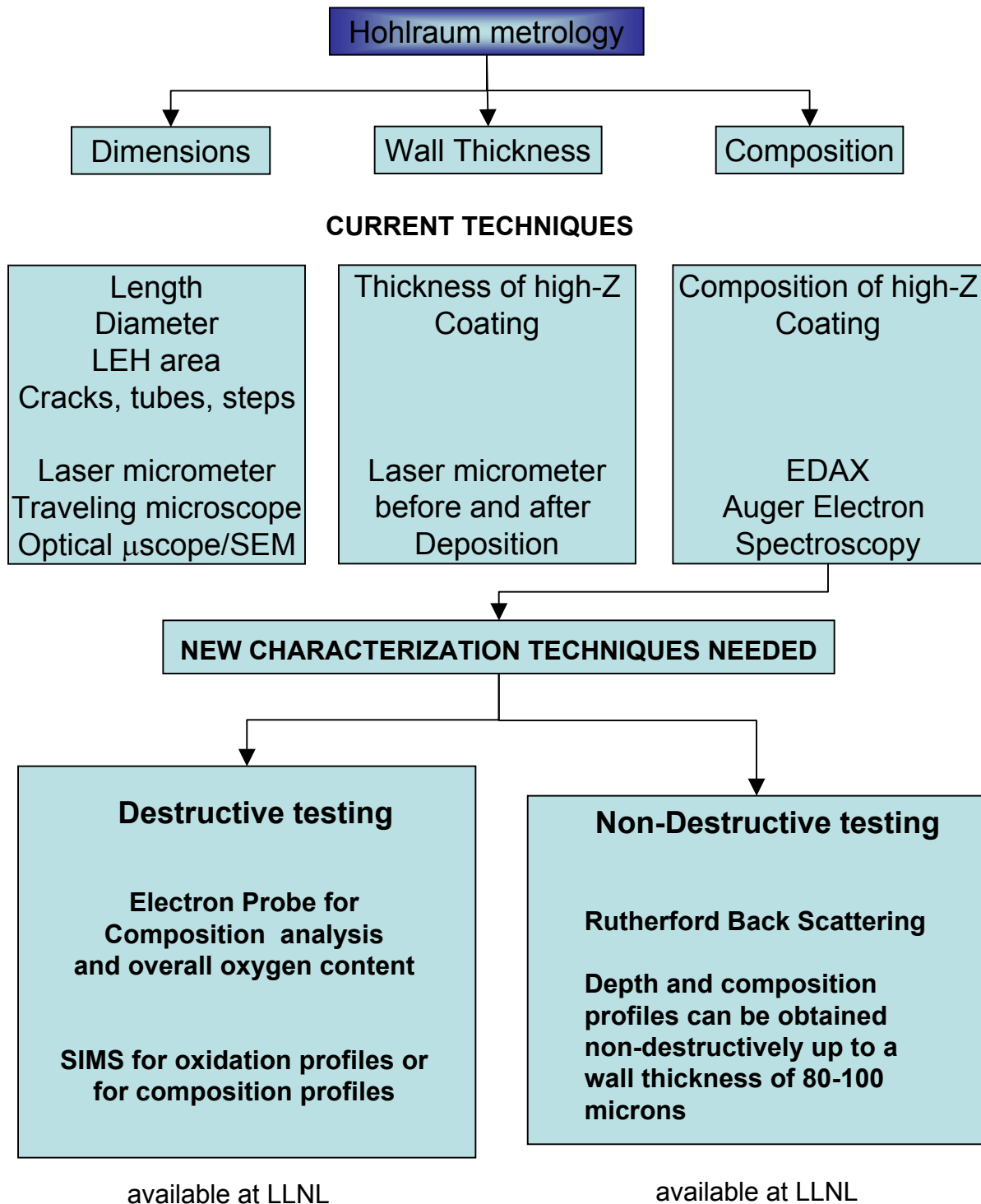


Figure 3: Flowchart for hohlraum metrology

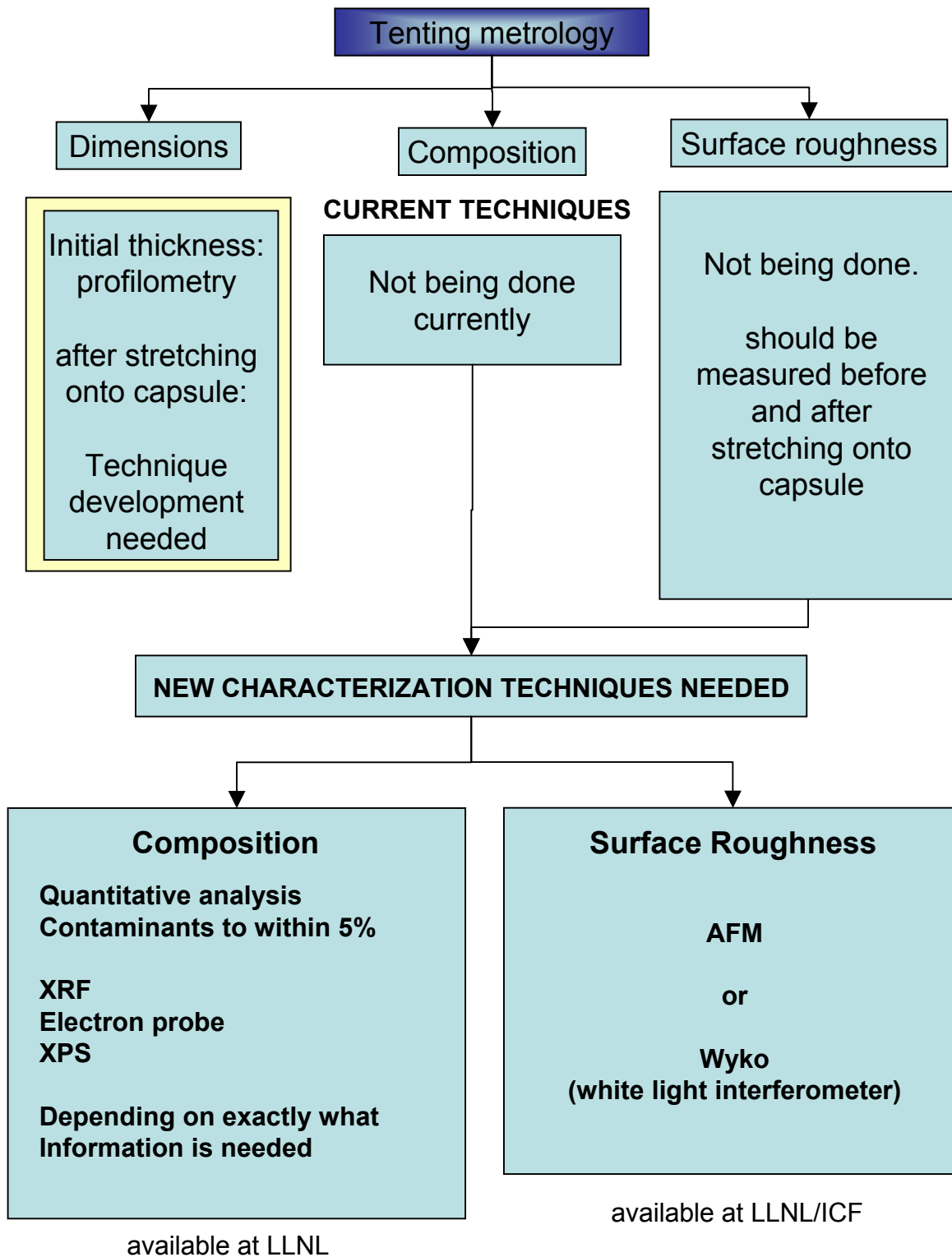


Figure 4: Flowchart for tenting metrology

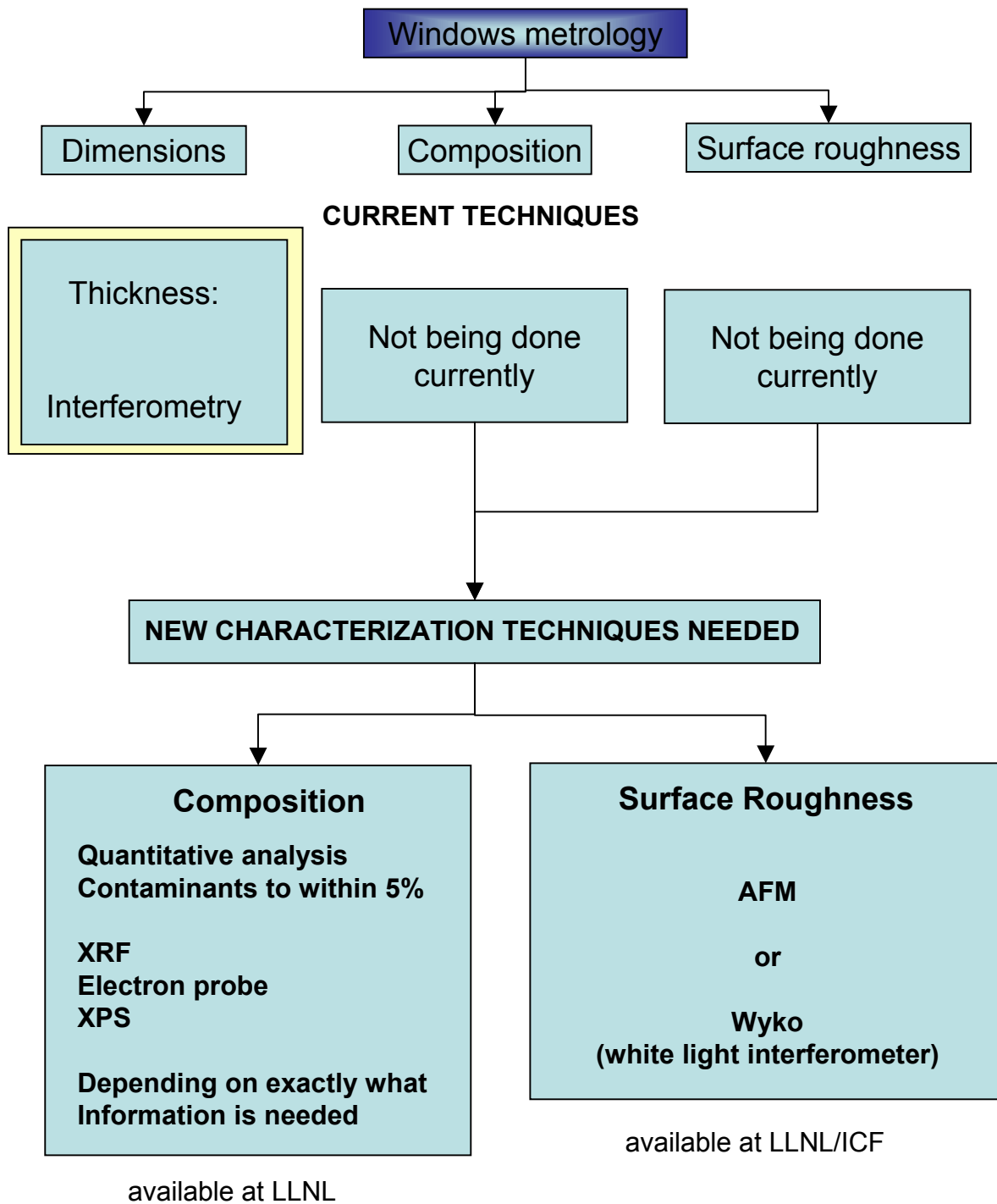


Figure 5: Flowchart for windows metrology

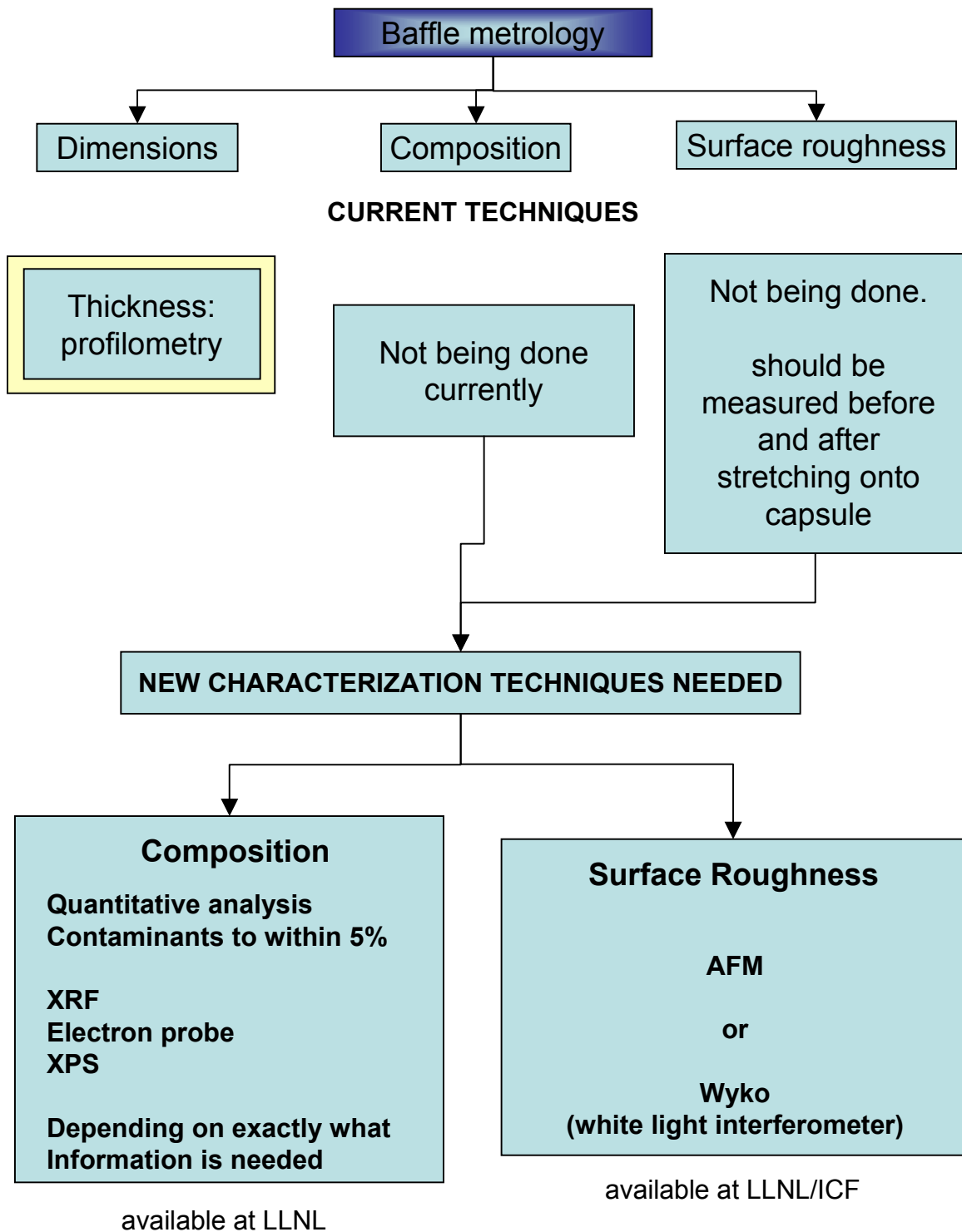


Figure 6: Flowchart for windows metrology



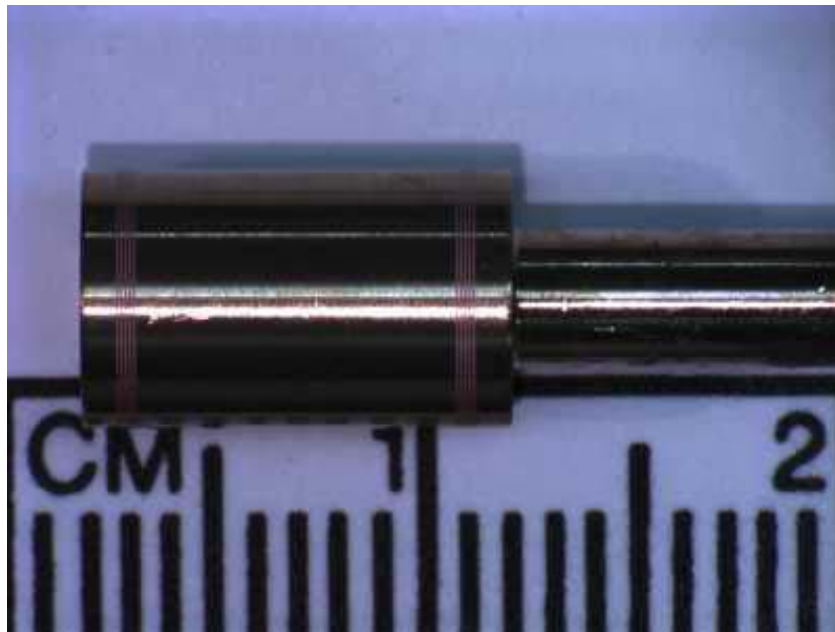


Figure 7: Images of Cu heater coils patterned on a test mandrel (stereo microscope)

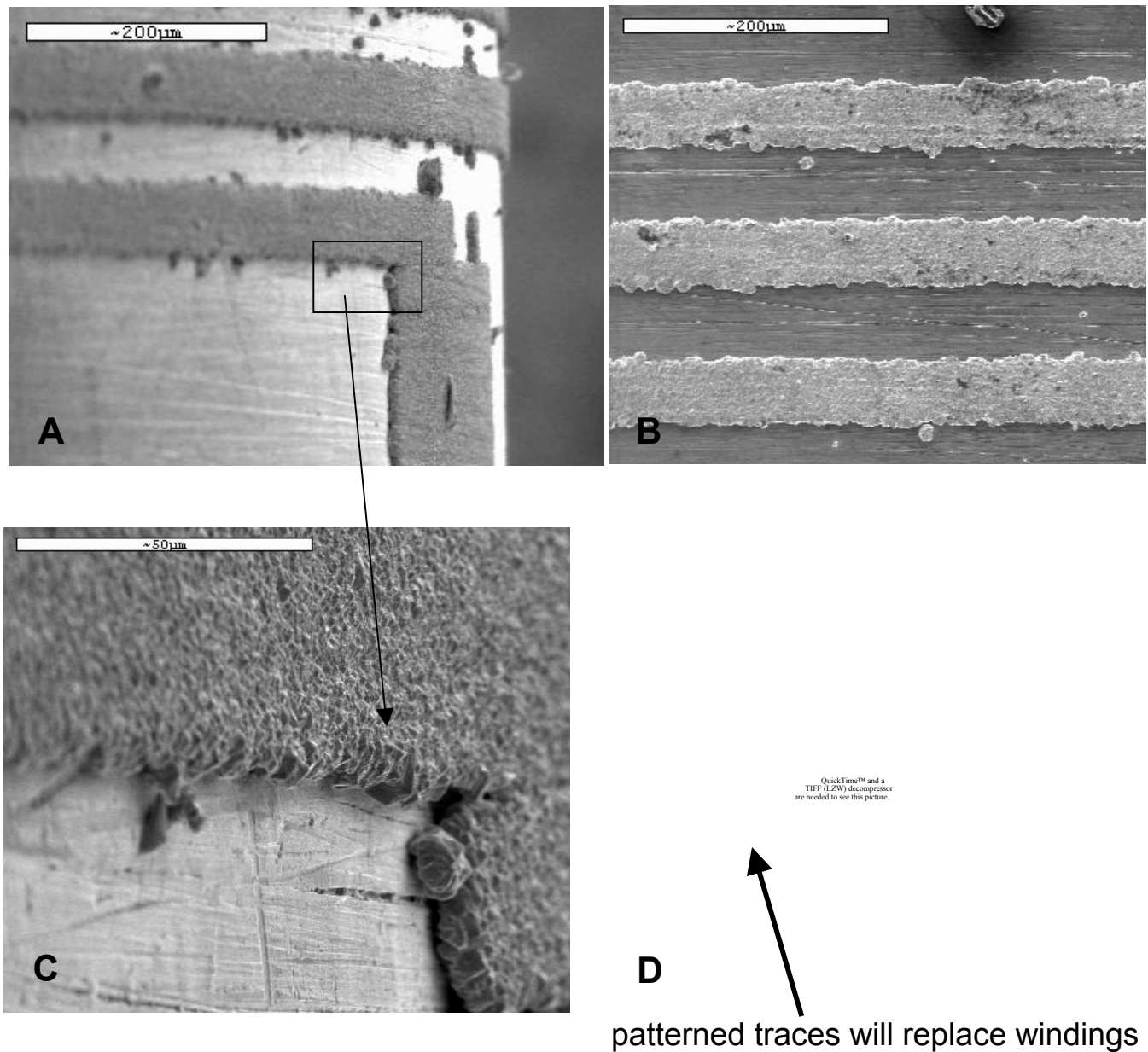


Figure 8: SEM images of the Cu lines on ta test mandrel

- A) Image taken near the end of the mandrel showing the larger Cu contact pad. A number of stray particles are seen in this image, showing that additional process improvements are needed. (scalebar = 200 μm)
- B) An additional view of the Cu traces. A large defect is seen in the upper right. (scalebar = 200 μm)
- C) A close-up of the indicated region in (A). This image shows poor adhesion of the Cu to the mandrel. More evident on the right side of the image. (scalebar = 50 μm)



replaces

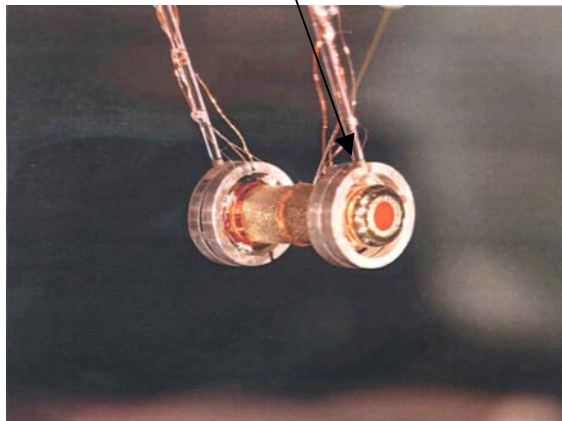


Figure 9: Image (top) of a Silicon cooling ring (stereo microscope) and A cryo hohlraum (bottom) showing where the new part will be placed.

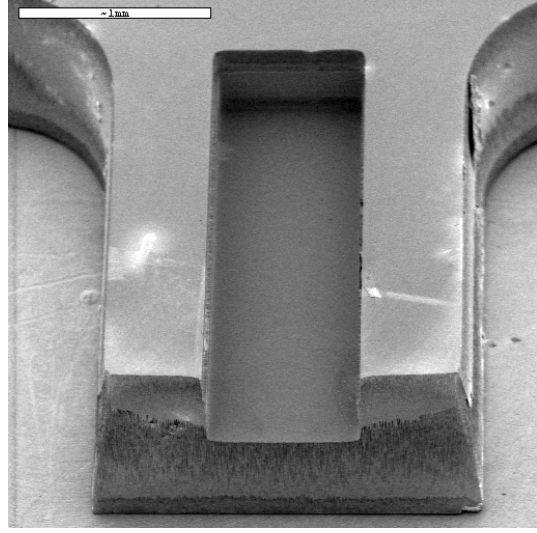
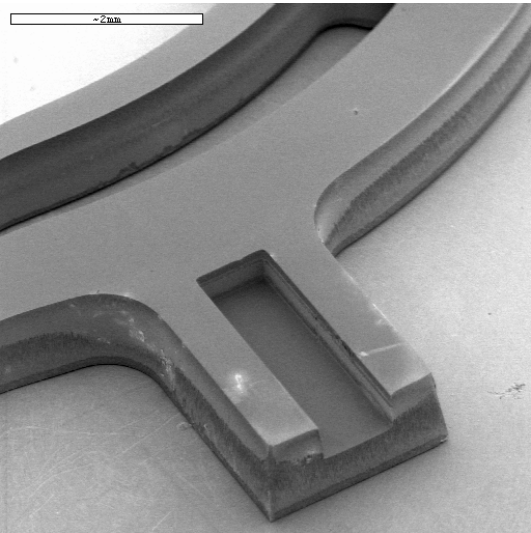
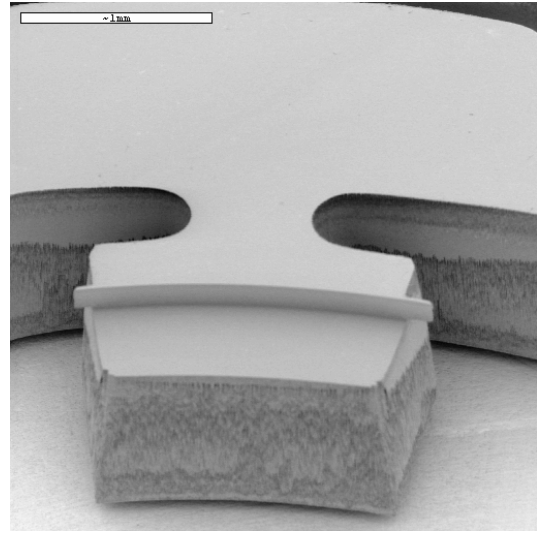
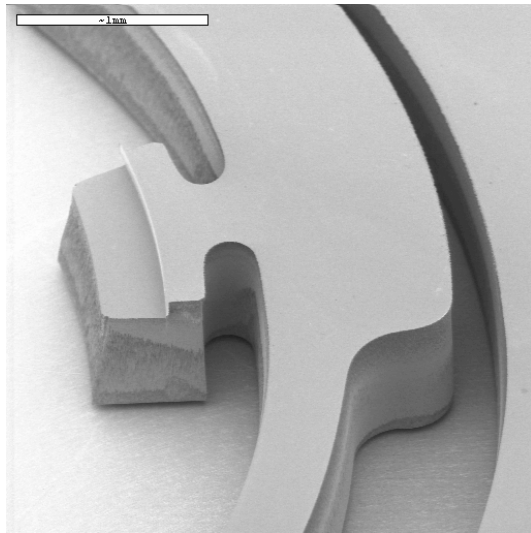
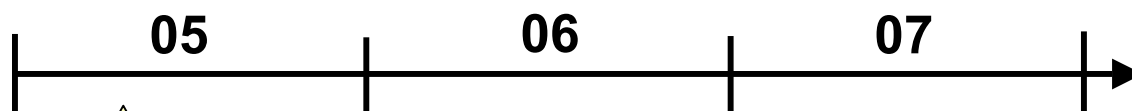
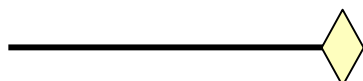


Figure 10: SEM Images (secondary  $e^-$  mode) of a Silicon cooling ring

# Hohlraum Characterization Timeline



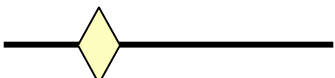
FY '05 Q1-Q2: Define specifications for cocktail hohlraum composition and Layer configuration (layer thicknesses, number of layers). Specify elements and tolerances for composition,



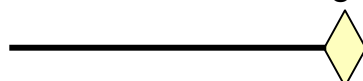
FY 05' Q2-Q4: Fabricate mock cocktail hohlraums and characterize the layer structure and oxidation behavior.



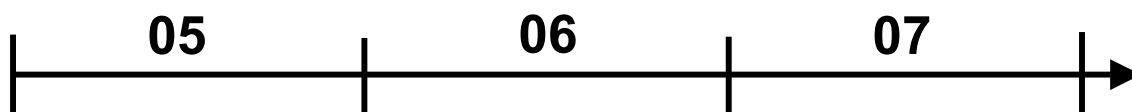
FY '05 Q1-Q2: Define specifications for windows, tent and baffle chemical composition.



FY '05 Q1-Q2: Define specifications for windows, tent and baffle chemical surface roughness



FY '06 Q1-Q4: Design a system for characterizing surface roughness of tents, windows and films after insertion into hohlraum assembly



FY '05, FY '06, FY'07: 1 FTE

FY '05: \$30-50k (re: XRF, CCD camera, radiography)

FY '06: \$150-\$200k  
New interferometry system

Figure 11: Hohlraum characterization timeline and associated expenses

Technique	Elements	Detection Limit	Depth Resolution	Imaging	Probe Size (lat.Resolution)
AFM	N/A	N/A	0.01 nm	Yes	1.5-5nm
Auger	Li-U	0.1-1 at%	2-6nm	Yes	100 nm
FIB	B-U (EDS mode)	0.1-1 at%	N/A	Yes	>3nm w/SEM >7nm w/FIB
SEM/EDS	B-U	0.1-1 at%	1-5 $\mu\text{m}$	Yes	4.5nm (SEM) 1 $\mu\text{m}$ (EDS)
SIMS	H-U	ppb-ppm	5-30nm	Yes	1 $\mu\text{m}$ (imaging) 30 $\mu\text{m}$ (depth)
TOF-SIMS	H-U	<1ppm	1 monolayer	Yes	0.1 $\mu\text{m}$
XPS/ESCA	Li-U	0.01-1 at%	1-10 nm	Yes	10 $\mu\text{m}$ -2mm
XRF	Be-U	10 ppm	N/A	No	100 $\mu\text{m}$ to ???

Figure 12: Chart depicting common analytical techniques and the associated detection limits, depth resolution and probe size.

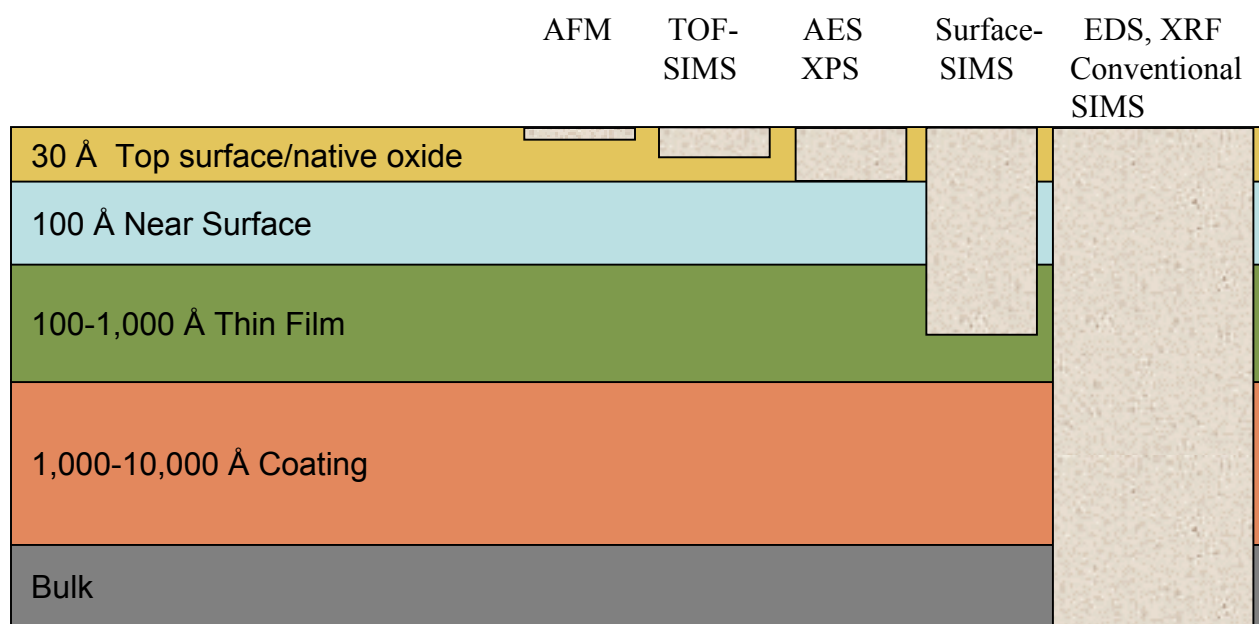


Figure 13: Schematic depicting the analysis depths associated with various techniques

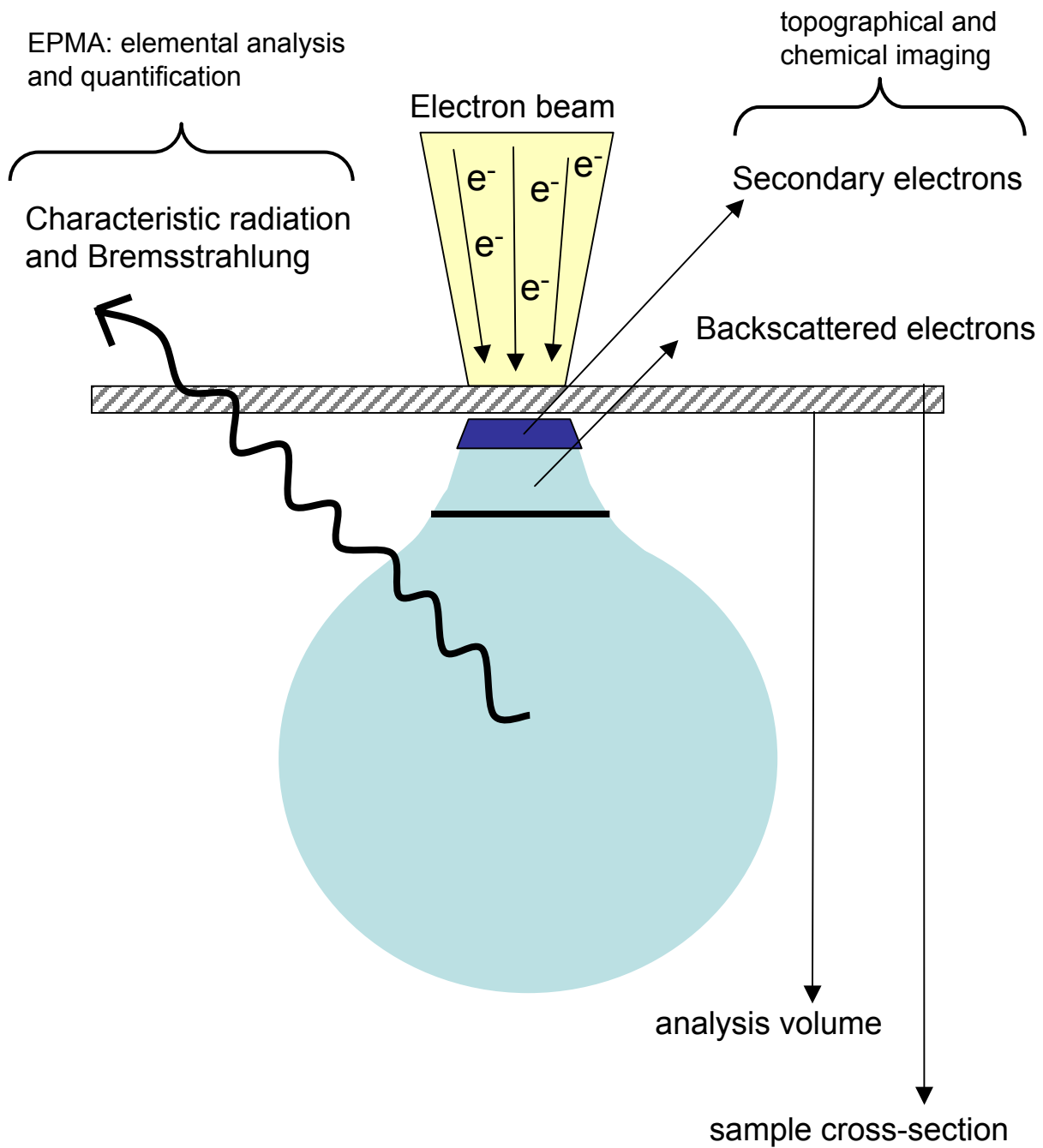


Figure 14: schematic depicting the scattering mechanisms analyzed with EPMA



<b>Feature:</b>	<b>EPMA / WDS</b>	<b>SEM / EDS</b>
Max. collection efficiency	~0.2%	2%
Quantum efficiency	~30%	~100% (2.5-15 keV)
Analysis time	Longer	Shorter
Spectral resolution	~10 eV	80-180 eV
Detection limit	100 ppm	1000 ppm
Typical peak to background	1000:1	100:1
Max. count rate <sup>1</sup>	A few 1000's cps	Can exceed 50,000 cps
Spectral artifacts <sup>2</sup>	Few if any	several

1. The count rate depends on a number of factors including probe current and thus probe size. These are provided as a general guideline.
2. There are a number of artifacts that can present a problem with EDS detectors. These include peak broadening, distortions, Si escape peaks, absorption, Si internal fluorescence peak, pulse-processing artifacts such as sum peaks and errors in dead time processing and susceptibility to stray radiation due to a larger solid angle of collection. The WDS method of detection is relatively free of these types of artifacts.

Figure 15: A comparison of some of the fundamental aspects of EPMA/WDS and SEM/EDS

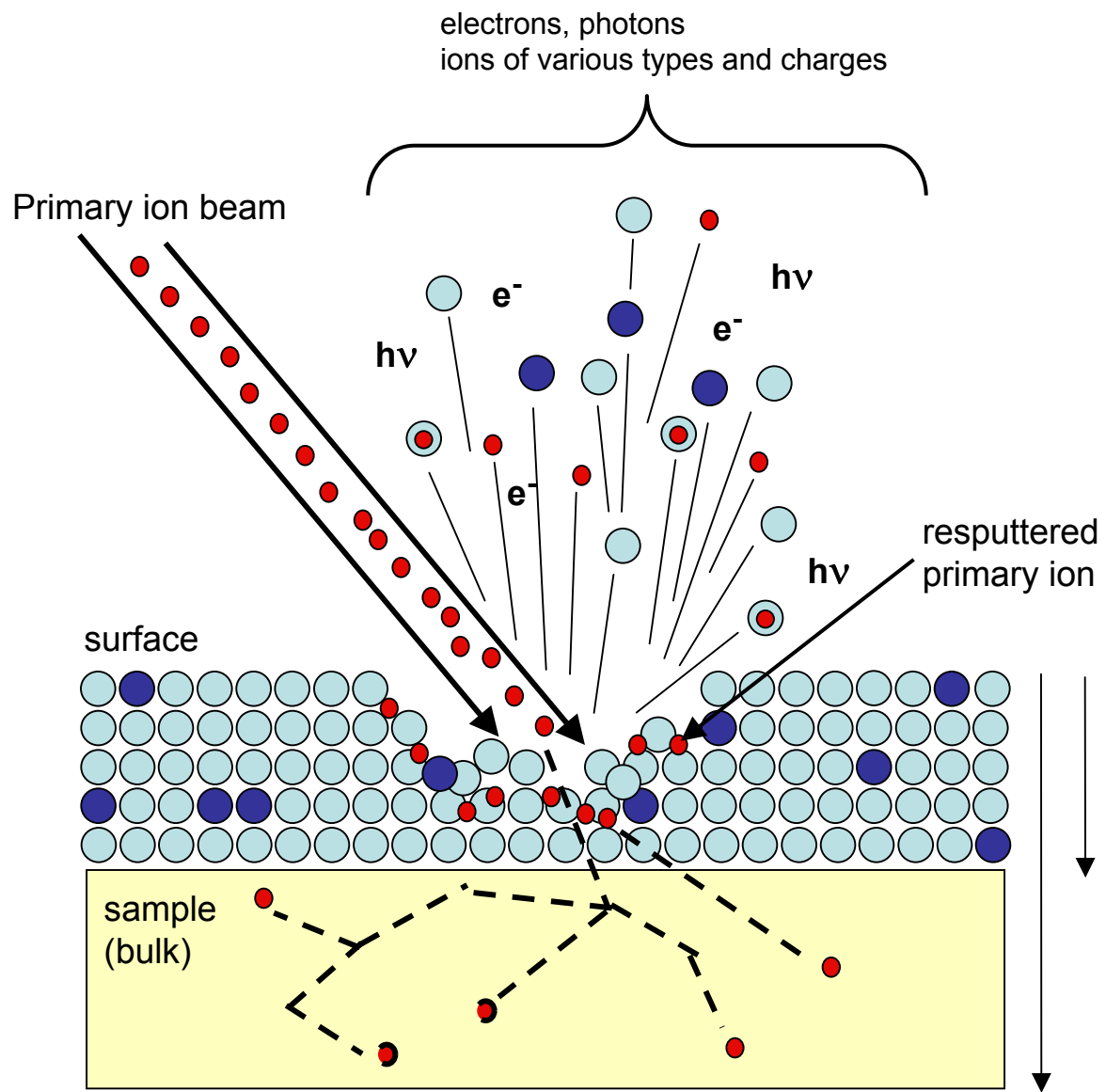


Figure 16: schematic depicting typical SIMS events when the primary ion beam impinges on the sample.

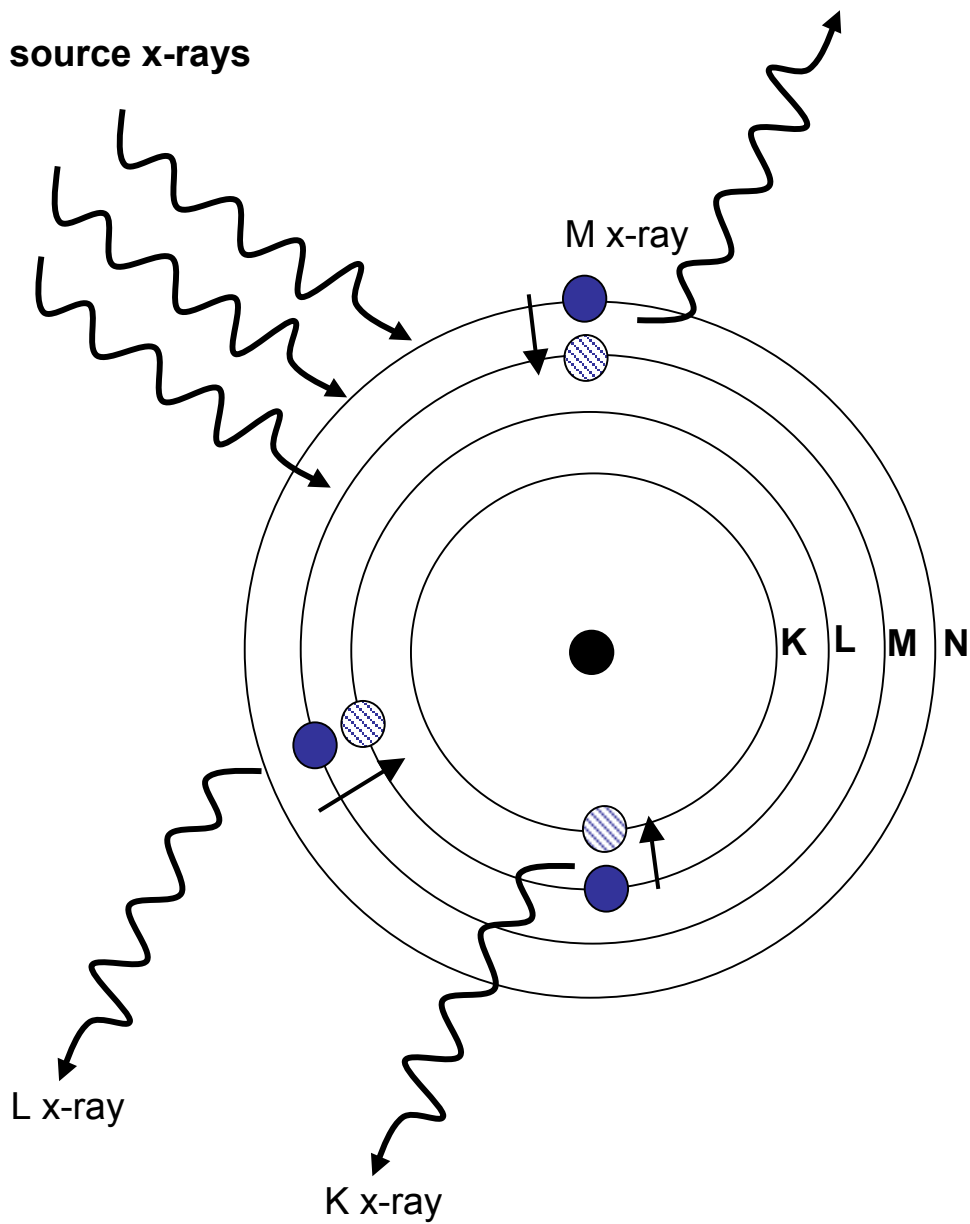


Figure 17: Schematic showing some of the possible transitions in an XRF experiment. The resulting secondary/fluorescent x-rays are analyzed in terms of energy and number to identify elements and their concentrations.

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